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EXPERIMENTAL INVESTIGATION OF DOUBLE PIPE HEAT EXCHANGER FITTED WITH DIFFERENT GEOMETRIES OF TWISTED TAPE

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ABSTRACT

This paper presents the experimental investigation on passive heat transfer enhancement technique in a double pipe heat exchanger fitted with different geometries of twisted tapes. The heat transfer was analyzed in a swirling flow condition by using twisted tape (TT), perforated twisted tape (PTT), perforated twisted tape with single V-Cut, and perforated twisted tape with double V-Cut under this experiment. The swirl motion created by the twisted tape allows for a large increase in the convective heat transfer coefficient, as well as an increase in the effective flow length. The plain tube has only primary flow but insertion of twisted tape will induce secondary flow that is perpendicular to the primary flow. The magnitude of secondary flow increases and furthermore V- Cut will increase magnitude of secondary flow. Hence the perforated twisted tape with double V-Cut showed higher heat transfer rate among all. Experimental results show the Reynolds number for perforated twisted tape with double V-Cut ranges from 3841.2 to 12203.6, and heat transfer improvement due to perforated twisted tape with double V-Cut became in the range of 1.77 to 2.34 times as compared to plain tube.

KEYWORDS: Heat Exchanger, Twisted Tape, Perforated Twisted Tape, Perforated Twisted Tape with Single V-Cut & Perforated Twisted Tape with Double V-Cut.

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Original Article

INTRODUCTION

Over the last few years, consumption of energy has increased because of urbanization, industrialization, population growth; therefore, researchers have been developed the energy saving techniques and the effective utilization of the available energy. Nowadays, heat transfer enhancement techniques are very important for designing different industrial types of equipment such as; refrigeration system, solar system, chemical process, air-conditioning, cryogenic, heat recovery system, thermal system, etc. So, effective utilization of the available energy is necessary for our daily life.

R.M. Manglik and A.E. Bergles (1993) conducted an experiment by using twisted tape inserts in a dual tube heat exchanger. For internal flow in the horizontal tubes, they considered a homogeneous wall temperature. Three different geometries of TT with TRs of 3, 4.5, and 6 were used in the experiment. The working fluids were water and ethylene glycol, and the results were achieved for tape thickness 0.483 for all the cases. They concluded that by inserting the twisted tape in the tube will enrich heat transfer rate. TT inserts will increase the effective flow length, reduces hydraulic diameter, and induce swirl motion.

To increase heat transmission, Sneha Ponnada et al. (2019) used aluminium TT with perforation of thickness 0.8 mm and width 12.5 mm. They also compared the outcomes after adjusting the axis. By bending the tape 90 degrees at a distance of 100 mm, the other axis was created. This tape has a length of 2600mm and is put in

a copper test section. They came to the conclusion that perforated TT has greater thermal performance than plain TT, however it is less when compared to alternate axis. When compared to plain tube, perforated TT showed a 44.3% increase and alternative axis showed a 48.12 % increase.

Hasanpour et al. (2014) experimentally examined in which they evaluated the performance of TT inserts. Hasanpour's major goal was to assess the total enhancement ratio (OER). In their experiment, they looked at a number of twisted tape models and discovered that OER was larger than unity.

Ahmad et al. (2020) considered different geometry of twisted tape by making circular, rectangular, diamond, triangular, square cut over the twisted tape. They also considered non-perforated TT. The experiments were done for discontinuous and continuous conditions. Total 9 cuts were made for all geometries of TT. They stated that the discontinuous turbulator is superior to the continuous TT, also concluded that discontinuous TT with circular cut will give better result among all continuous and discontinuous configuration and cut geometries.

Naga Sarada et al. (2010) investigated heat transfer by keeping condition of flow turbulent in a horizontally placed tube by considering air as the working fluid and used a varying width for the twisted tape. Heat transfer was improved by 36 percent to 48 percent for full width inserts and 33% to 39% for reduced width inserts when twisted tape inserts were compared to straight tube. Tubes with full width twisted tape inserts were found to have a higher overall enhancement ratio than tubes having reduced width TT inserts. They conclude in terms of material savings by adopting narrower twisted tapes.

Liu et al. (2013) analysed and compiled the most important experimental findings from studies conducted since 2004 that used TTEs, wire coils, and swirl flow generators. They concluded that TTEs are favoured for laminar flow applications, whereas other passive methods such as ribs, conical nozzles, and conical rings are better for turbulent flow conditions.

Hong and Bergles (1976) conducted the experiment by using ethylene glycol and water in electrically heated tubes. For fully developed swirl flow, they worked for the laminar flow state and developed the Nusselt number correlation.

Kumar et al. (2012) conducted extensive research on the use of twisted tape turbulator to increase heat transfer. They came to the conclusion that in the situation of laminar flow, twisted tape performs better. Also by surface modification or geometry modifications, the results of twisted tapes can be improved. It will also boost the heat transfer rate in turbulent and also in laminar flows with low frictional coefficients.

K. Sivakumar et al. (2020) employed triangular and circular cuts over twisted tape to do CFD analysis while keeping the depth of the triangle cut and the diameter of the circular cut both at 5mm. Nusselt number was 1.3 percent higher for triangular cut and 1.1 percent higher for circular cut, according to CFD research. The Reynolds number was discovered in the range of 5710 to 18300. When comparing the Nusselt number for a triangle cut to the value obtained for a circular cut over twisted tape, they discovered that the Nusselt number for a triangle cut is larger. They also found that triangular cut twisted tapes had a 27.3 percent greater value than plain tube, while circular cut twisted tapes had an 18.2 percent greater value.

Kumar et al. (2020) studied the rate of heat transfer and pressure loss in a circular channel using a twisted tape with circular-cuts tube with peripheral circumferences on single V-cut and double V-cut configurations. They concluded in their experimental study, with a twist ratio of 2, twisted tape boosts the thermal performance factor by 1.69.

Nakhchi and Esfahani (2019) numerically analysed the thermal efficiency for turbulent flow arrangement in a heat exchanger. By using double V-cut twisted tapes with a Reynolds number of 5000, they were able to improve heat transfer by up to 117 percent.

Abolarin et al. (2019) examined the effect produced by the twisted tape with continuous U-shaped cutting, as well as the effect of a ring being inserted. They studied the heat transmission and pressure decrease in a circular channel and discovered that as the cutting depth ratio increases, the transition from laminar to transient happens quicker. In the transient regime, increasing the cutting depth ratio often increases the heat transfer rate.

Sarada et al. (2010) used twisted tapes of various pitch lengths to investigate heat transfer in a channel. They found that when twisted tapes are used instead of plain tubes, the heat transmission rate increases. The increased heat transfer is owing to the centrifugal force generated by spiral motion.

Khoshvaght Aliabadi et al. (2020) analyzed thermal performance in a heat exchanger having double tube. They also inserted twisted tape in the tube and finally made a conclusion that the twisted tape gives more heat transfer when it is compared to heat exchanger without tape inserts.

Azher M abed et al. (2018) worked on TT and TT with V-cut and numerically analysed that the performance of TT and V- cut was found superior to the plain tube. The Reynolds number was found in the range of 4000 to 9000 and the heat flux varies from 5000 to 1000 W/m^2. Two different twist ratios : 4 and 6 were taken into consideration and it was seen that thermal performance factor for lesser twist ratio is found to be better. For twist ratio 4 it came 4.45 while for TR 5 it was 4.19. So, they concluded by keeping minimum twist ratio the performance will be advantageous. They also suggested that the V- cut will give better heat transfer as compare to perforate when the twisting parameters are same.

Singh and Kumar (2020) conducted an experiment in which they focused on the influence of a dimpled TT on heat transfer rate. They also analyzed numerical pressure drop in a double tube heat exchanger. They discovered that raising the dimple diameter from 3 to 5 mm, and then from 5 to 7 mm, decrease the creation of vortices and flow stuck at the bottom of the dimples.

Zhang et al. (2019) experimentally examined the influence of a self-rotating turbulator with circular hole on heat flow rate and pressure drop. As a result, they came to the conclusion that perforated rotating twisted tapes outperformed perforated non-rotating twisted tapes in terms of performance.

Ranjith and Shaji K (2016) numerically investigated on a dual tube heat exchanger using twisted tape. They considered swirl motion on hot and cold both side. The numerical analysis was carried for two different twist ratios 5 and 3 under turbulent circumstance. They finalise that twisted tape has improved the heat flow rate on both annulus and tube. The pressure drop also increases but overall enhancement ratio is found around one so it can be considered as advantageous.

J.D. Moya-Rico et al. (2020) also investigated characterization of a double tube heat exchanger by fitting TT. They performed 320 experiments by varying the parameters such as flow velocity, twisted tape pitch, free spacing, etc. The correlation for Nusselt number was obtained by using minimum variance method. They also found the correlation for

friction factor. As a working fluid, a solution of water and sugar was utilised. The Nusselt number as well as friction factor was greater for shorter spacers, according to the results. In terms of free spacing length, they found correlations for Nusselt number as well as friction factors.

Several researches have been conducted on passive heat transfer improvement strategies. The most effective tape inserts are twisted tape inserts. Twisted tapes with cuts at the central area were used by some researchers, and some of them made it to the periphery. In present study to improve heat flow, a combinations of cuts at the central (core) and peripheral regions (both periphery) was used. Circular cut of 8mm was done at the central region of the twisted tape and both side V-cut was done at the peripheral region. This allowed for better fluid mixing at the periphery and core regions, resulting in improved heat transfer.

EXPERIMENTAL SETUP

The experiments was carried by using four different configuration of twisted tapes : which are plain twisted tape inserts (TT), perforated twisted tape inserts (PTT), perforated twisted tape with single V-Cut inserts (PTTVC), and perforated (circular-cut) twisted tape with double V- cut inserts (PTTDVC). Each case had a pitch of 95 mm. The experimental set-up used in this experiment is depicted in Figure. 1.

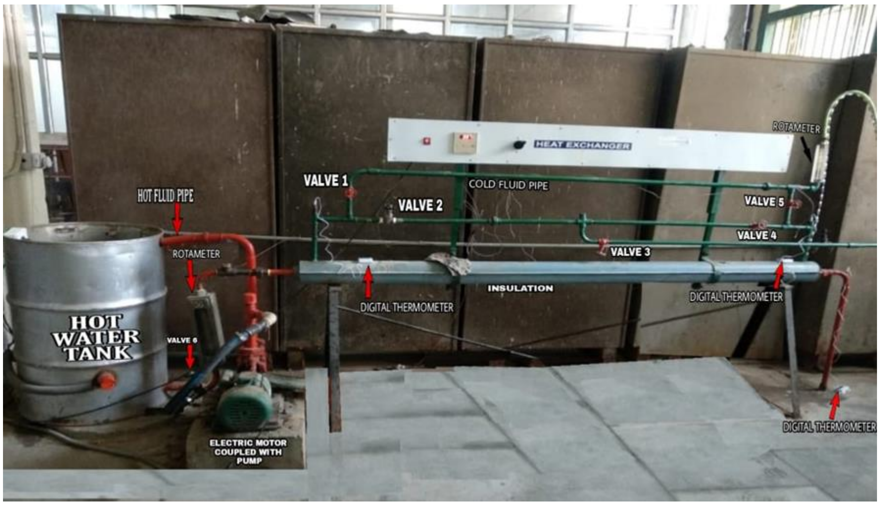

Figure 1: Experimental setup of Heat Exchanger.

The experiment was carried out by maintaining a steady temperature in the hot water inlet and a constant mass flow rate of cold water. The inlet temperature of hot water was maintained at 60°C with the aid of a thermostat, and the mass flow rate of cold water was set at 270 litres per hour with the help of a rota-meter in this experiment. The inner tube is made of copper, and the annulus is made of cast iron. The hot water tank, which holds up to 200 litres of water, was filled up to 150 litres. To heat the bath, three water heaters were installed in the tank's bottom. During the entire experiment, the counter flow arrangement was considered by opening Valve-1, Valve-3, and Valve-4 and closing Valve-2 and Valve-5. Valve-3 was used to set a fixed mass flow rate of cold water 4.5 litters/min, and Valve-6 was used to set a variable mass flow rate of hot water 2 to 6 litters/min. The electric motor and pump were turned on when the temperature of the hot water reached 50°C. The pump drew hot water from the tank and circulates it through a copper tube (inner tube). The annulus allows cold water to flow into it (space between hot water and cold water pipe). The rota-metre was used to set the mass flow rate of cold water at 270 litres per hour. The hot water mass flow rate was first set at 2 litres per minute.

The thermostat detected the temperature of the hot water until it exceeds 60°C and gave a signal to the electric contactor. The power supply was automatically turned off by the contactor. The reading shown by the digital thermocouple was noted after the steady state had been achieved. The hot water mass flow rate was set at 2.5 litres per minute, while the cold water mass flow rate was kept constant. Same process was repeated and reading had been taken up to mass flow rate of hot water reached 6 LPM. The reading had been taken for plain tube heat exchanger. Further, readings had been taken heat exchangers with plain twisted tape inserts, double tube heat exchangers with perforated twisted tape inserts, double tube heat exchangers with perforated twisted tape along with single V-cut at the periphery, and perforate twisted tape with double V-cut at the periphery. The inlet and outlet temperatures of hot water, as well as the inlet and outlet temperatures of cold water were recorded. Total 9 readings had been taken for one complete set by altering hot water mass flow rate in the range of 2-6 litres per hour with an increment of 0.5.

RESULTS AND DISCUSSIONS

In this section the experimental results achieved in various circumstances i.e. plain tube heat exchanger, twisted tape inserts, perforated twisted tape inserts, perforated twisted tape with single V- cut, and perforated twisted tape with double V- cut were compared by creating a graph between the Nusselt numbers and the Reynolds number.

Effect of Plain Twisted Tape

The comparison of nusselt number over different reynolds number for plain tube and twisted tape inserts is shown in the Figure.2.

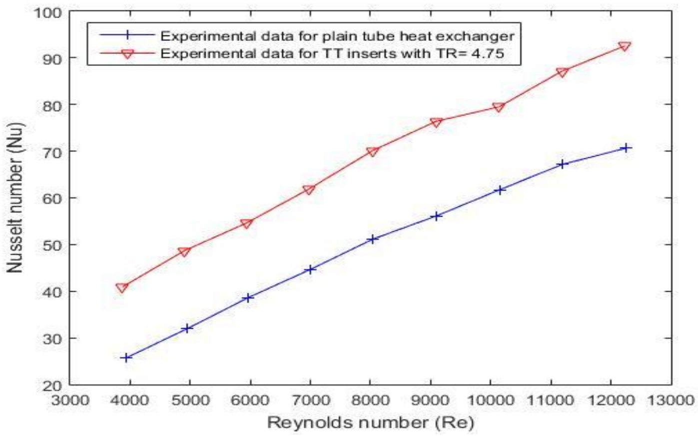

Figure 2: Comparison of Nusselt Number between Plain tube and Tube with Twisted Tape Inserts.

The experimental result shows that nusselt number for twisted tape inserts is higher than plain tube inserts over a different values of reynolds number. Moreover, Nusselt number increment achieved in the experiment was in the range of 28.83 % to 59.95 %. Furthermore, the percentage increment in nusselt number is not linearly dependendent on the mass flow rate.

Effect of Perforated Twisted Tape

The comparison of nusselt number over different reynolds number for twisted tape and perforated twisted tape inserts is shown in the Figure.3.

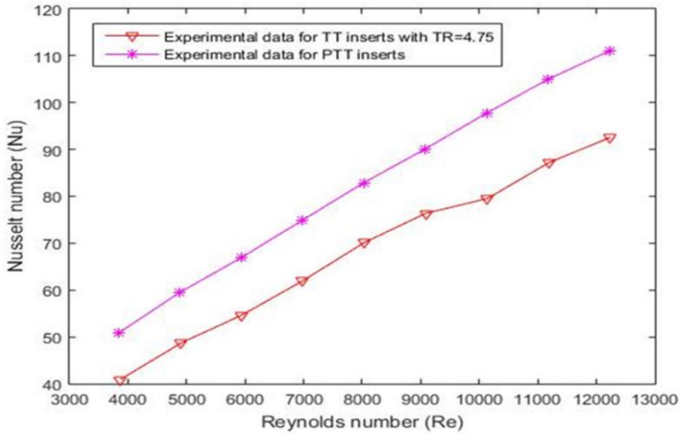

Figure 3: Comparison of Nusselt Number between Twisted Tape and Perforated Twisted Tape Inserts.

The experimental result shows that nusselt number increases with reynolds number. Moreover, the Nusselt number of twisted tape having circular holes is higher as compared to twisted tape inserts. In detail, the Nusselt number for perforated twisted tape inserts was found to be greater by 19.99 % to 24.52 % as compared to twisted tape inserts. Furthermore, the nusselt number of heat exchanger with perforated twisted tape insert is increased from 1.57 to 1.987 times as compared with plain tube.

Effect of Perforated Twisted Tape with Single V-Cut

The comparison of nusselt number over different reynolds number for perforated twisted tape and perforated twisted tape with single V-cut inserts is shown in the Figure.4.

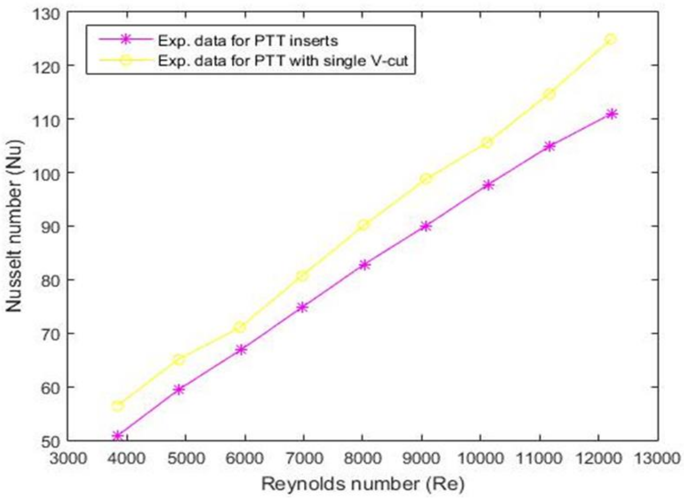

Figure 4: Comparison of Nusselt Number between Perforated Twisted Tape and Perforated Twisted Tape with Single V-cut.

Experimental result shows that perforated twisted tape with a single V-cut has a higher nusselt number than perforated twisted tape inserts. In detail, the nusselt number of perforate twisted tape with a single V-cut is found to be larger in the range of 6.34 to 12.53% as compared to perforate twisted tape inserts. Moreover, the nusselt number of heat

exchanger with perforate twisted tape with a single V-cut insert is increased in the range of 1.57 to 1.987 times as compared to plain tube.

Effect of Perforated Twisted Tape with Double V-Cut

The comparison of nusselt number over different reynolds number for perforated twisted tape with single V-cut and double V-cut inserts is shown in the Figure.5.

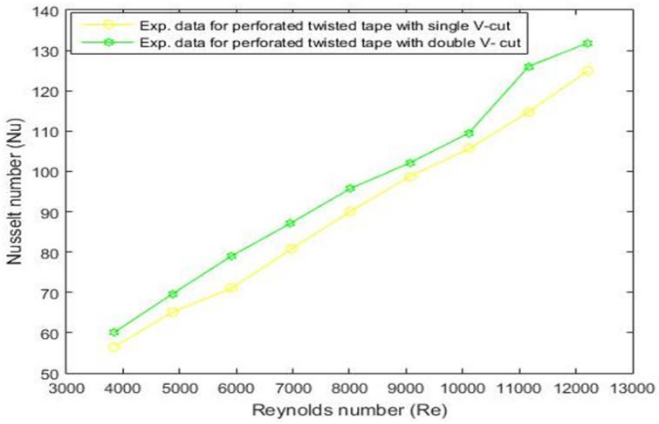

Figure 5: Comparison of Nusselt Number between Perforated Twisted Tape with Single V-Cut and Perforated twisted Tape with Double V-Cut.

Experimental result shows that perforated twisted tape with a single V-cut has higher nusselt number as compared to perforated twisted tape with double V-cut. In detail, the nusselt number of double V-cut is higher than single V-cut in the range of 3.37% to 11.09%.

CONCLUSIONS

The use of twisted tape with various geometrical alterations to improve heat transfer is presented in this paper. The primary objective of this article is to use perforated twisted tape with a double V-cut to improve the heat transfer rate of a double tube heat exchanger. To compare the results, the experiments were performed using plain tube (PT), plain tube with twisted tape (TT) inserts, plain tube with perforated twisted tape (PTT) inserts, and plain tube with perforation and V-cut. The V-cut was preserved at a depth of 6mm and a breadth of 4mm. A circular hole with an 8mm diameter was also preserved at the centre of the twisted tape. The primary fluid motion provides greater fluid while the secondary fluid motion, which includes swirl flow and depth of cut, improves convective heat transfer through mixing. The value obtained from the experimental investigation for nusselt number was found to be 1.873 to 2.34 times in double tube with perforated double V-cut inserts as compared to tube without inserts.

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